Goddard Multi-Scale Modeling with Unified Physics

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Introduction

Recently, a multi-scale modeling system with unified physics was developed at NASA Goddard. It consists of (1) the Goddard Cumulus Ensemble model (GCE), a cloud-resolving model (CRM), (2) the NASA unified Weather Research and Forecasting Model (WRF), a region-scale model, and (3) the coupled fvGCM-GCE, the GCE coupled to a general circulation model (or GCM known as the Goddard Multi-scale Modeling Framework or MMF). The same cloud microphysical processes, long- and short-wave radiative transfer and land-surface processes are applied in all of the models to study explicit cloud-radiation and cloud-surface interactive processes in this multi-scale modeling system. This modeling system has been coupled with a multi-satellite simulator for comparison and validation with NASA high-resolution satellite data. The left figure shows the multi-scale modeling system with unified physics. The GCE and WRF share the same microphysical and radiative transfer processes (including the cloud-interaction) and land information system (LIS). The same GCE physics will also be utilized in the Goddard MMF.

The idea to have a multi-scale modeling system with unified physics is to be able to propagate improvements made to a physical process in one component into other the components smoothly and efficiently. In this poster, we will demonstrate the validity of this concept.

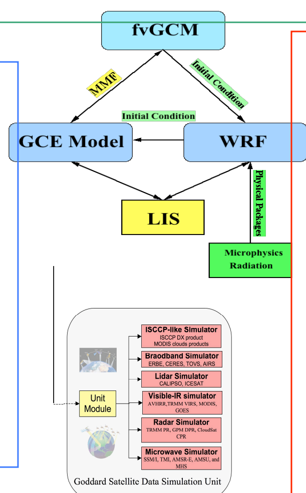
Multi-Scale Model Components

NASA MMF
Goddard fvGCM – GCE Model
2 x 2.5 degree (*13,104 CRMs*)
Microphysics (>40 processes)
Positive definite advection scheme
1.5 order TKE
Radiation (every 3 min)
Time step (10 s)
28 vertical layers (32 in fvGCM)
V – Component (no PGF)
Online cloud statistics (every 2 min)
270 hours/per simulated year on a 512 CPU computer

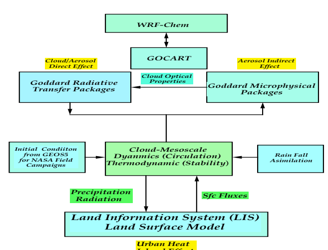
The third component of the modeling system couples the NASA Goddard finite volume GCM (fvGCM) with the GCE model (known as the Goddard MMF). The use of the fvGCM allows for global coverage and the use of the GCE for the explicit simulation of subgrid cloud processes and their interaction with radiation and surface processes. This modeling system has been applied to the study of climate scenarios such as the 1998 El Nino and 1999 La Nina. The new coupled modeling system results in the more realistic propagation and intensity of tropical rainfall systems and intra-seasonal oscillations and an improved diurnal variation of precipitation; all are difficult to capture using even state-of-the-art GCMs with subgrid convection schemes. The new Goddard MMF is the second MMF developed worldwide following the one at CSU. Despite differences in model dynamics and physics between the Goddard and CSU MMFs, both simulate stronger MJOs, better cloudiness (high and low), single ITCZs and more realistic diurnal rainfall patterns than traditional GCMs. Both MMFs also have similar biases, such as a summer precipitation bias (relative to observations and to their parent GCMs) in Asian monsoon regions. However, there are notable differences between the two MMFs. For example, the CSU MMF simulates less rainfall over land than its parent GCM, which is why it simulates less global rainfall than its parent GCM. The Goddard MMF simulates more global rainfall than its parent GCM because of a high contribution from its oceanic component.

The GCE model, a CRM, has been developed and improved at NASA Goddard Space Flight Center over the past two and a half decades. The ability of the GCE model to simulate the impact of atmospheric aerosol concentrations on precipitation processes was recently enhanced (Tao *et al.* 2007) as were its abilities to account for the effects of land (Zeng *et al.* 2007) and ocean surface processes on convective systems in different geographic locations (Wang *et al.* 2003; Tao *et al.* 2004; Zeng *et al.* 2008). The GCE model's bulk microphysical scheme were recently modified to reduce the over-estimated and unrealistic amount of grauple in the stratiform region (Tao *et al.* 2003; Lang *et al.* 2007), to better address saturation issues (Tao *et al.* 2003) and to obtain more realistic ice water contents for longer-term simulations (Zeng *et al.* 2008, 2009). Recently, the GCE model has been adapted to interface with a couple of other bulk microphysical schemes, namely the single and double moment versions of the Colorado State University (CSU) Regional Atmospheric Modeling System's (RAMS's) bulk microphysical scheme (Meyers *et al.* 1997; Saleeby and Cotton 2004), and a spectral bin microphysical scheme (Khain *et al.* 2004; Tao *et al.* 2007; Li *et al.* 2009a&b). The development and main features of the GCE model were published in Tao and Simpson (1993) and Tao *et al.* (2003). A review on the application of the GCE model to better understand precipitation processes can be found in Tao (2003).

Parameters/ Processes	GCE Model
Dynamics	Anelastic or Compressible 2D (Slab- and Axis-symmetric) and 3D
Vertical Coordinate	Z (height)
Microphysics	2-Class Water & 3-Class Ice 2-Class Water & 2-Moment 4-Class Ice Spectral-Bin Microphysics
Numerical Methods	Positive Definite Advection for Scalar Variables; 4th-Order for Dynamic Variables
Initialization	Initial Conditions with Forcing from Observations/Large-Scale Models
FDDA	Nudging
Radiation	k-Distribution and Four-Stream Discrete-Ordinate Scattering (8 bands) Explicit Cloud-Radiation Interaction
Sub-Grid Diffusion	TKE (1.5 order)
Surface Energy Budget	Force-Restore Method 7-Layer Soil Model (PLACE) Land Information System (LIS) TOGA COARE Flux Module
Parallelization	OPEN-MP and MPI

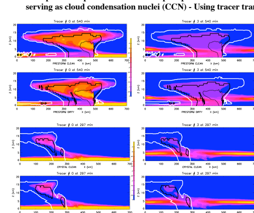

fvGCM
MMF
Initial Condition
Initial Condition
GCE Model
WRF
LIS
Physical Packages
Microphysics
Radiation
Unit Module
ISCCP-like Simulator
ISCCP DX product
MODIS clouds products
Braodband Simulator
ERBE, CERES, TOVS, AIRS
Lidar Simulator
CALIPSO, ICESAT
Visible-IR simulator
AVHRR,TRMM VIRS, MODIS, GOES
Radar Simulator
TRMM PR, GPM DPR, CloudSat CPR
Microwave Simulator
SSM/I, TMI, AMSR-E, AMSU, and MHS
Goddard Satellite Data Simulation Unit

The second component of the modeling system is WRF (Michalakes *et al.* 2001), a next-generation mesoscale forecast model and assimilation system developed at NCAR along with several NOAA and DOD partners. The model is designed to support research advancing the understanding and prediction of mesoscale precipitation systems. It incorporates advanced numerics and data assimilation techniques and has a multiple re-locatable nesting capability as well as improved physics. WRF will be used for a wide range of applications, from idealized research to operational forecasting, with an emphasis on horizontal grid sizes in the range of 1-10 km. Various Goddard physical packages (i.e., CRM-based microphysics, radiation and land-surface hydrology processes) as well as a real-time forecast system using Goddard Earth Observing System (GEOS) global analyses that have been developed at NASA have recently been implemented into WRF (left figure). The CRM-based packages have improved forecasts (or simulations) of convective systems [e.g., a linear convective system in Oklahoma (International H2O project, IHOP-2002), an Atlantic hurricane (Hurricane Katrina, 2005), high latitude snow events (Canadian CloudSat CALIPSO Validation Project, C3VP 2007), a snow event over Japan Sea (2001), a heavy orographic-related precipitation event in Taiwan (Summer 2007) and Typhoon Morakot (2009)]. In addition, two other GSFC modeling components have been coupled to the GSFC WRF representing the land surface (i.e., the Land Information System or LIS) and aerosols [i.e., the WRF Chemistry Model and Goddard Chemistry Aerosol Radiation and Transport Model (GOCART)].


WRF-Chem
GOCART
Cloud/Aerosol Direct Effect
Aerosol Indirect Effect
Cloud Optical Properties
Goddard Radiative Transfer Packages
Goddard Microphysical Packages
Initial Condiiton from GEOS5 for NASA Field Campaigns
Cloud-Mesoscale Dyanmics (Circulation) Thermodynamic (Stability)
Rain Fall Asimilation
Precipitation Radiation
Sfc Fluxes
Land Information System (LIS) Land Surface Model
Urban Heat Island Effect

Application Examples

An important aspect of aerosol-cloud-precipitation interaction is the origin of the aerosols serving as cloud condensation nuclei (CCN) - Using tracer transportation as an indicator

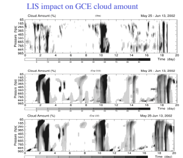


The **stronger, organized systems like the PRESTORM squall case** are able to transport a significant amount of near surface pollutants into the upper troposphere (over **65**%). The majority of aerosols come from lower levels, entering into clouds via cloud base.

A significant amount of aerosols at mid-levels can be entrained via cloud sides (e.g., the CRYSTAL case). The amount of **mid-level entrainment** varies with storm type (i.e., updraft intensity and storm longevity).

GCE-LIS and WRF-LIS Coupling System

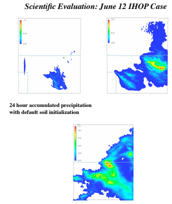
LIS impact on GCE cloud amount



Twenty-day cloud simulation is done in Oklahoma in 2002 and its cloud amount is evaluated with ARM observations. Upper panel shows observed cloud amount. Middle and low panel modeled cloud amount with ARM and LIS surface fluxes as input, respectively. The results from numerical experiment with LIS capture observed cloud and precipitation processes especially for less-organized convective clouds. Adapted from *Zeng et al*. [2007].

LIS Spin-up Impact on WRF+LIS Precipitation

Scientific Evaluation: June 12 IHOP Case



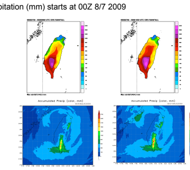
24 hour accumulated precipitation with default soil initialization

Observed Radar Derived Surface Precipitation (Source: NOAA/NCEP)

48 and 72 h accumulated precipitation (mm) starts at 00Z 8/7 2009

Typhoon Morakot struck Taiwan on the night of Friday August 7th, 2009 as a category 2 storm with sustained winds of 85 knots (92 mph). Although the center made landfall in Hualien county along the central east coast of Taiwan and passed over the central northern part of the island, it was southern Taiwan that received the worst effects of the storm where locally as much as 2000 mm (2 m) of rain were reported, resulting in the worst flooding there in 50 years. Nearly the entire southern half of the island has in excess of 1000 mm of rain. Within that are two areas in excess of 2000 mm along the western slopes of the central mountain range. The result of the enormous amount of rain has been massive flooding and devastating mudslides. More than 600 people are confirmed dead.

High-resolution (2-km) WRF with improved microphysics will be used for simulate this typhoon case. The improved microphysical scheme captured both in terms of maximum rainfall area and intensity (left figures and table). The model also found that the heavy amounts of rain over the southern portion of the island is due to persistent southwesterly flow associated with Morakot and it's circulation was able to draw up copious amounts of moisture from the South China Sea into southern Taiwan where it was able to interact with the steep topography.



Observed and WRF simulated accumulated surface rainfall (mm). The top two panels are the observed 48- (left) and 72-h (right) observed rainfall (based on dense rain gauge network). The bottom two panels are with 2 km grid spacing with improved microphysics at corresponding 48- (left) and 72-h (right) WRF simulations.

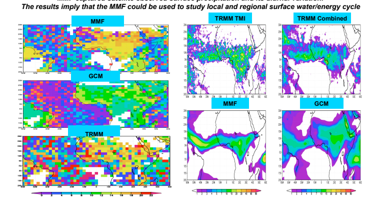
Microphysical schemes	48 – hours Maximum Rainfall (mm)	72-hours Maximum Rainfall
3ICE-Hail with reduced Evaporation	**2867**	**3307**
3ICE-Graupel	**2856**	**3345**
3ICE – Graupel Improved	**2396**	**2942**
Warm Rain Only	**1589**	**2000**
Observation	**2134**	**2434**

The maximum rainfall simulated by model with different Goddard microphysical options. Observed maximum rainfall is also shown for comparison.

Monthly precipitation and local time of precipitation frequency maximum over West Africa

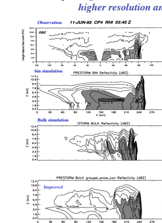
MMF captured satellite observed surface precipitation and its diurnal variation.

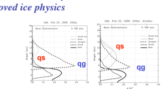
The results imply that the MMF could be used to study local and regional surface water/energy cycle



Monthly precipitation rates (mm/day) over West Africa for September 1999 from TRMM observations (TMI, top-left, and Combined, top-right) and simulations from the Goddard MMF (lower-left panel) and the GCM (lower-right panel).

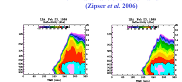
Improving the Simulation of Convective Cloud Systems: higher resolution and improved ice physics





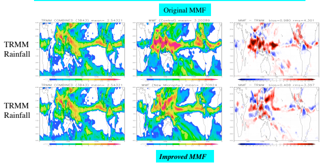
Lang *et al*. (2007): 3ice-graupel WRF3.1

Climatologically, 40-dBZ penetrations above 10 km are rare even over land (Zipser *et al.* 2006)



Lang *et al*. (2009): 3ice-graupel Goddard WRF3.1

Impact of GCE new microphysics on MMF simulated rainfall



Lang et al. 2007 improved the GCE bulk microphysical scheme based on precipitation radar reflectivity dataset from TRMM LBA field campaign observations in Brazil. This scheme has been implemented into the MMF to understand its impacts on seasonal and climate simulations. It is found that the new microphysics lead to more realistic precipitation ice contents and hydrometeor structures in the MMF. The total precipitation amount in tropical areas from the new scheme agrees with TRMM observation better than the corresponding control run. The excessive precipitation over the western Pacific in the original scheme has been reduced significantly.

Current-Future Model Improvements (NEWS, MAP and PMM)

- Model Improvements
  - Complete the MMF and LIS coupling to study the interaction between cloud systems and land surface processes
  - Complete the MERRA and CRM/SCM coupling
  - Implement an improved microphysics in CRM that is embedded within MMF
  - Investigate the impact of terrain effect on MMF's performance
  - Couple with 3D GCE MPI, GEOS5, an ocean mixed model, and an Non-hydrostatic GCM
  - Improve the MMF cloud dynamics and test many different MMF configurations
  - Couple the MMF model with the Satellite Data Simulation Unit (SDSU) to identify the strengths and weaknesses of the model microphysical processes.
- Scientific Applications
  - Conduct 11-year (1998-2008) MMF integrations and examine the physical processes associated with diurnal variation of cloud/precipitation over land
  - **Examine the explicit cloud-aerosol-radiation interactions (GOCART)**
  - Investigate the flood/draught and hurricane events in USA
  - Investigate the impact of surface processes on weather/climate events in local, regional scale

MMF (1998, 1999, May 2005 to September 2007), WRF and GCE cloud data is current available through Goddard web site: http://portal.nccs.nasa.gov/cloudlibrary/index2.html